AR-010-643

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Service History of the F-111 Wing Pivot Fitting Upper Surface Boron/Epoxy Doublers

Peter Chalkley and Rowan Geddes

DSTO-TN-0168

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Peter Chalkley and Rowan Geddes

Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Several of the boron/epoxy doublers applied to upper surface of RAAF F-111C wing-pivot-fittings (WPFs) have disbonded. Based on RAAF records, a total of seven wings (out of forty to which doublers have been applied) have confirmed disbonds: A15-3, A15-5, A15-10, A15-14, A15-19, A15-20 and A15-284R. Most of the disbonds are forming in the smaller forward doubler (five confirmed) although three aft doublers have also disbonded.

This report documents the service history of all doublers applied to RAAF F-111Cs. The current investigation suggests that disbonds in the boron/epoxy doublers on the upper surface of F-111 WPFs are forming within 1000 AFHRS service. However, infrequent inspections of the doublers make a precise determination difficult. Issues such as the use of external wing tanks on some aircraft (especially RF111C's), disbond initiation sites and below tolerance wing skin thicknesses are investigated.

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Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia

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AR-010-643
September 1998

APPROVED FOR PUBLIC RELEASE

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Executive Summary

From January 1989 to September 1990 AMRL-designed boron/epoxy doubler sets were applied to forty RAAF F-111C wings. The adhesively-bonded boron/epoxy doubler reinforcements were applied to the upper surface of the wing pivot fittings (WPFs) of F-111C wings for two purposes: 1) to reduce yielding in WPF stiffener runout number two (SRO2) during the cold proof load test and so reduce subsequent SRO2 structural integrity problems and 2) to increase the inspection interval on SRO2 and so reduce RAAF's maintenance burden. In the cold proof load test the entire aircraft is subjected to load in a hangar maintained at -40°C and the structural integrity of the brittle D6AC steel components established. Since application the doublers have seen up to fifteen hundred flight hours of service. This report documents the service history of the forty doubler sets applied.

RAAF experience has been that although most doublers survive the cold proof load test many are failing in less than one thousand hours of flight service. Failure takes the form of disbonds in or near the adhesive layer. Fractographic evidence suggests that the disbonds are fatigue induced. RAAF records for every wing have been examined and seven wings have recorded disbonds. The doublers are extremely difficult to non-destructively inspect because they are covered with a mutlilayered protective sheath. Doubler disbonds are commonly found when the sheath itself has failed and is then removed and inspection of the doublers becomes possible. Consequently it is difficult to be certain about the state of the other doublers and RAAF no longer considers that the doublers are serving purpose two above.

The aim of the report is to document the extent of the problems with the boron/epoxy doublers and to investigate any commonality in the service history of the those wings with failed doublers that may suggest a cause. Issues such as the use of external wing tanks on some aircraft (especially RF111Cs), disbond initiation sites and below tolerance wing skin thicknesses are investigated

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Rowan Geddes joined AMRL as a PO1 in August 1998, and has completed both a degree in Aerospace Engineering (hons) and an Associate Diploma of Aerospace Systems Engineering at RMIT. He is an active committee member of the Melbourne Branch of the Royal Aeronautical Society. Rowan is currently working with the Composites Functional Area at AED, AMRL.

Contents

1. Introduction

This report documents the service history of boron/epoxy doublers applied to the upper surface of RAAF F-111 wing-pivot-fittings (WPFs). Section 2 describes the fitment history of the doublers and their purpose. Section 3 describes the history of detection of disbonds in some doublers and has rough estimates of the remaining life before detection of defects in the others. Salient points are given in the conclusion.

RAAF currently have 21 F-111C strike-reconnaissance aircraft and 42 wings, of which 40 wings have had boron/epoxy doublers fitted to the WPFs. Four F111Cs were fitted with reconnaissance pods and are designated RF-111s. RAAF also acquired 16 F-111Gs from the USAF but these do not have doublers fitted.

The boron/epoxy doublers, designed at AMRL, were fitted to lessen yielding in WPF stiffener run out number 2 (SRO2) during the cold proof load test (CPLT). Lessening the yielding is expected to reduce the likelihood of cracking in the critical SRO2 region. A second, unrealised, benefit of the patch was to be the increase of the inspection interval for SRO2 from 525 to 1025 airframe hours (AFHRS). Details of the boron/epoxy doublers and the CPLT can be found in reference 1.

The doubler service histories documented in this report are based on RAAF records. These records are a minimum of nine months out of date so that the wings may have up to 200 AFHRS more than reported here. Doubler service histories have been found for 40 of the 42 wings.

2. Doubler Fitment History

2.1 Cold Proof Load Test

The wing of an F-111 aircraft is able to vary its sweep angle from 16 degrees through to 72.5 degrees for supersonic operations. The wing pivot operates at extremely high stresses and as a consequence high-strength D6AC steel is used in the wing pivot fitting and wing carry through box.

D6AC steel is very notch sensitive and susceptible to fatigue cracking. The critical crack size for D6AC is smaller than can be detected by conventional non-destructive inspection (NDI) means. To overcome this a test was devised by General Dynamics in which the entire airframe was cooled to -40°C and loaded to proof load conditions (hence CPLT designation). At this extreme temperature and loading conditions it was possible to detect any flaws in the critical wing pivot region before catastrophic failure in flight.

The CPLT is carried out on all RAAF F-111 aircraft after every 2025 AFHRS of service.

2.2 WPF Upper Boron/Epoxy Doublers

During early CPLT strain surveys of the wing pivot fitting, it was found that SRO2 experienced very high strain readings. To lessen the strain in the region, boron doublers were designed and applied to the area.

The doublers were designed to CPLT load conditions at AMRL [1] in 1987. After some early teething problems with the application of the patches, they were progressively applied to all wings in the fleet from September 1990 (wing BA15-3) through to July 1995 (wing A15-12).

Documentation for 40 of the 42 wings has been obtained. Personnel at 501 Wing Amberley, Queensland, carried out all boron doubler modifications (RAAF mod 7214-003-414).

2.3 Service History of Boron/Epoxy Doublers

Most of the RAAF wings with doublers have seen between 4100 and 6100 hours of service. Since the application of the doublers, the wings have seen between 193 and 1565 hrs of service with the majority falling between 500 and 1500 hrs of service (Fig 1.)

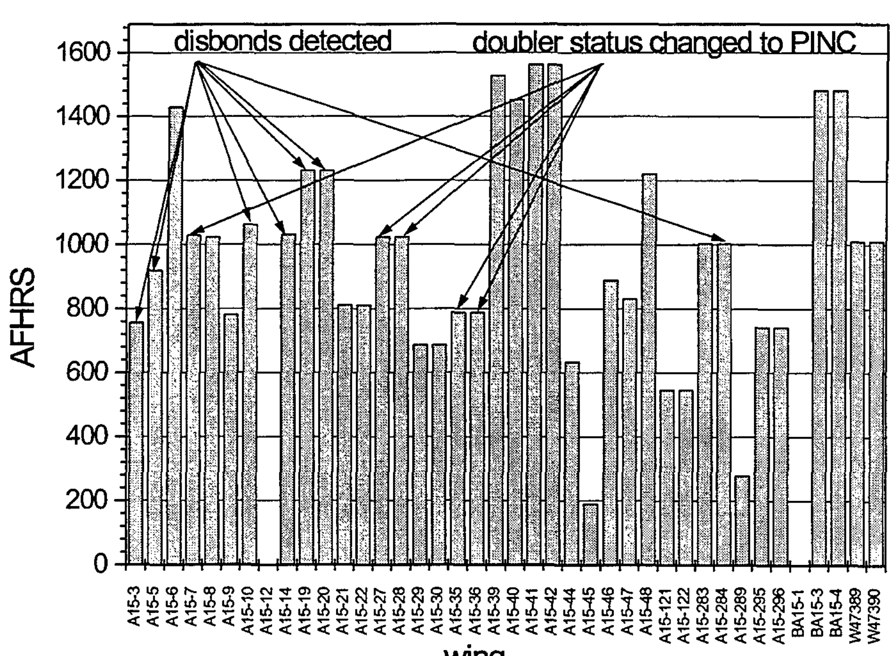

Figure 1. Hours of service of boron doublers since fitment.

Note that some doublers have many more AFHRS than those found to be disbonded. However, because of the infrequent inspection of the doublers it cannot be assumed that these doublers have no disbonds. The two doublers with zero AFHRS of service probably failed during CPLT.

Table 1 gives more detailed information the doubler fitment dates and AFHRS of service. In some cases the disbonds have been detected in the doublers and this is noted. In other cases the status of doublers in the wing history sheets has changed from INC (incorporated) to PINC (partially incorporated) and this is designated PINC in the comments column. Doublers having a PINC status have usually suffered some failure during CPLT.

Table 1. Doubler Fitment and Disbond Detection History.

Wing no.	Doubler install AFHRS date	AFHRS at install	Date disbond found	AFHRS at disbond detected	AFHRS to disbond detected	Doubler AFHRS since fitment (at 8-Jun-98)	Comment
A15-3	28-Nov-91	3824.7	5-Feb-96	4584	759		FWD doubler has disbonds (Pell report [2]). Plate thickness under size-Molent [3]
A15-5	16-Apr-91	3983.2	29-Jun-95	4906.6	923		FWD and AFT doubler disbonds, teardown wing
A15-6	16-Apr-91	3983.2				1432	
A15-7	6-Jun-89	3918	9-May-95	4950	1032		PINC-Possible failure of doubler during CPLT
A15-8	30-Jun-89	3919				1026	
A15-9	31-May-90	3221est.				784	
A15-10	31-May-90	3221.2	11-Sep-95	4286.2	1065		AFT doubler disbonds
A15-12	19-Jul-95	4679	19-Jul-95	4679			Possible CPLT failure
A15-14	13-Jul-92	4414.8	24-Jun-97	5449	1034.2		FWD doubler disbond (AMRL has doublers)
A15-19	9-Mar-92	4387.6	31-July-95	5620.8	1233.2		FWD doubler disbond (AMRL has doublers)
A15-20	9-Mar-92	4387.6	31-Jul-97	5620.8	1233.2		FWD doubler disbonds
A15-21	1-Jun-93	3730				813	
A15-22	1-Jun-93	3730				813	
A15-27	18-Jan-89	3955.7	19-Jan-95	4981.6	1025.9		PINC-Reason for failure of doubler unknown
A15-28	18-Jan-89	3955.7	19-Jan-95	4981.6	1025.9		PINC-Reason for failure of doubler unknown
A15-29	5-Jul-94	4500.6				689	
A15-30	12-Jul-94	4500.6				689	
A15-35	17-May-90	4000.7	19-Jan-95	5325.5	790.2		PINC - CPLT failure, (ref. AIR1/4080/A8/1101-5 Pt 5)
A15-36	17-May-90	4000.7	19-Jan-95	5325.5	790.2		PINC-CPLT failure, (ref. AIR1/4080/A8/1101-5 Pt 5)
A15-39	28-Sep-90	4220				1530	
A15-40	28-Sep-90	4220				1455	
A15-41	29-Oct-91	3553				1565	
A15-42	31-Oct-91	3553				1565	
A15-44	9-May-95	4449.8				636	
A15-45	26-Oct-93	5168.2				193	Difficult to reconcile this with next
A15-46	26-Oct-93	4470.2				891	
A15-47	31-Jul-91	4513.4				833	
A15-48	11-Jul-91	4513.4				1222	
A15-121	14-Jan-94	5160.5				549	
A15-122	14-Jan-94	5160.5				549	
A15-283	1-Jun-92	5062.4				1006	
A15-284	29-Jul-92	5064.7	3-Apr-98	6068.7	1006.3		FWD and AFT doublers disbonds
A15-289	3-Sep-96	5449				281	
A15-295	14-Jan-94	4732.7				745	
A15-296	7-Jul-94	4732.7				745	
BA15-1	19-Jul-91	1351	19-Jul-95	1351.6			Possible CPLT failure
BA15-3	8-Oct-90	2764				1483.7	
BA15-4	8-Oct-90	2764				1483.7	
W47389	4-Jun-91	4057.2				1012.7	
W47390	4-Jun-91	4057.2				1012.7	

3. Doubler Disbonds

3.1 History of disbond detection

There have been seven RAAF documented cases (Table 1) of wings with boron/epoxy doubler disbonds including the wing intended for teardown inspection A15-5 (Fig 2). The disbonds were detected between 759 and 1233 AFHRS of service. However, many other wings have seen AFHRS of service within this range and greater (Figure 1) without reports of disbonds. This, however, may be because of infrequent inspections.

There have also been five cases of doubler status changing from INC to PINC. In three cases some there some failure of the doublers during CPLT.

The first disbond was detected during repair of a fuel leak on airframe A8-126, wing A15-3, in February of 1996. This wing had seen 759 hrs of service before the disbond was discovered. A fractographic inspection of this wing was performed at AMRL by Robert Pell [2]. Fatigue of the adhesive was identified as a possible cause of the disbond. This wing has a plate thickness [3] near the aft doubler of only 0.225 inches compared to a fleet average of about 0.3 inches.

Three wings with disbonds have been fitted to RF-111C airframes. Consultation with the RAAF has shown that the RF variants typically carry large external fuel tanks on the outboard pivoting pylons more often than the standard F-111C's. Each of these fuel tanks carries 600 gallons of fuel and is over 2.5 meters long. The total weight of a pylon, tank and fuel is 4770lbs. This could have a marked effect on the torsion and bending loading of the wing and the measured strains at the wing pivot-fitting region. EE360 history is being sort from the RAAF to establish which aircraft have carried external fuel tanks during the period that their doublers have been fitted.

3.2 Types and location of disbonds

Typically, the disbonds occur in the forward doubler, however there have been three cases of the aft doubler disbonding. Two types of disbonds generally occur [2]: disbonding in the adhesive bondline caused by cohesive fatigue of the adhesive and intraply delamination of the layer of the boron/epoxy doubler adjacent to the bondline. Earlier fractographic studies [2] and recent visual inspection of fracture surfaces from other wings suggest that disbonds initiate by fatigue of the adhesive at the doubler outboard edge and then after some inboard growth move into the first ply of the boron/epoxy doubler. Evidence of fibre failure, probably occurring during CPLT, has been found in wings A15-5 and A15-35 and is shown later in this section.

Figures 2 and 3 show schematic disbond maps (with stiffener positions overlays) for wing A15-5 (the teardown test wing) recorded 509 AFHRS apart. Only outboard disbonds are shown. The complete ultrasonic inspection at 923 AFHRS doubler service - RAAF NDISL record 501/A08C/11-01/A15-5/G Pt1 (11) – is shown in Appendix A.

Also shown in Appendix A are the results of a recent ultrasonic inspection of A15-5 doublers by AMRL staff (AED - FFDA F-111/Wing/01) conducted to RAAF NDISL AAP 7214.003-36-1. Disturbingly, these results show extensive disbonding emanating from the inboard edges of the AFT and FWD doublers. However, tap testing did not support these results. A central section of the FWD doublers also appeared disbonded according to ultrasonic testing but once again tap testing did not support this result.

Figure 2 shows the outboard results of a tap test carried out by ex-RAAF NDI technician Wade Farley on wing A15-5 after 1432 AFHRS of doubler service.

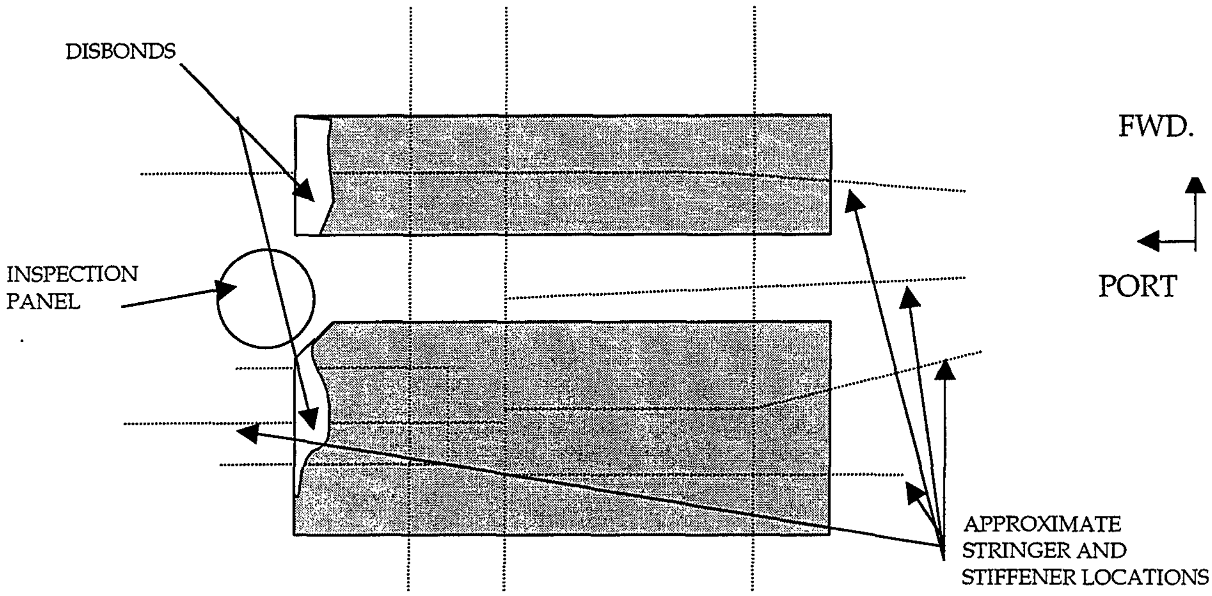

Figure 2. Location of outboard edge disbonds in A15-5 as indicated by tap testing - July 98 (1432 AFHRS doubler service).

Figure 3 shows a schematic of outboard disbonds from an earlier ultrasonic inspection by RAAF NDISL (ref 501/A08C/11-01/A15-5/G Pt1 (11)).

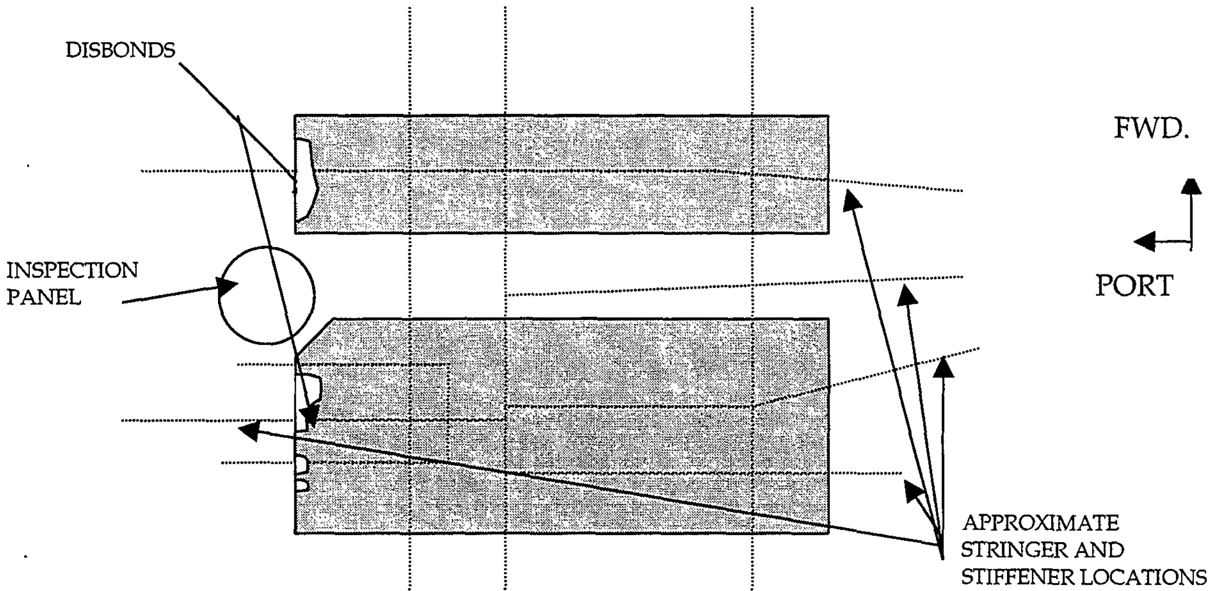

Figure 3. Schematic of outboard-edge disbonds in A15-5 doublers from RAAF ultrasonic inspection (923 AFHRS doubler service).

Figure 3 shows that the FWD doubler disbonds started at the centre and travelled inboard and also outwards towards the forward and aft edges. Similar behaviour was seen in the AFT doubler. The initiation sites may coincide with stiffener positions. Further disbond records are being sort from the RAAF to clarify this possibility.

Fibre fracture has been found (Figures 4,5,6) at the central corners of the inboard edges of both the AFT and FWD doublers in wing A15-5. There is some evidence of similar failure in A15-35.

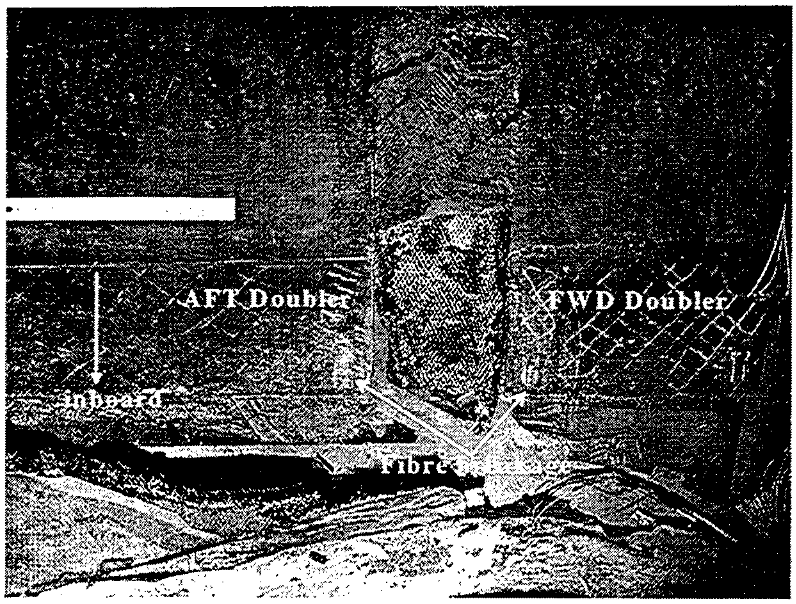

Figure 4. Overview of the inboard edges of the A15-5 doublers.

As shown in Figures 5 and 6 the central corners of the inboard edges of the A15-5 doublers exhibit fibre breakage. This breakage may have occurred during CPLT.

Figure 5 shows the central corner of the inboard edge in greater detail. The path of the fibre breakage is show by an offset white line.

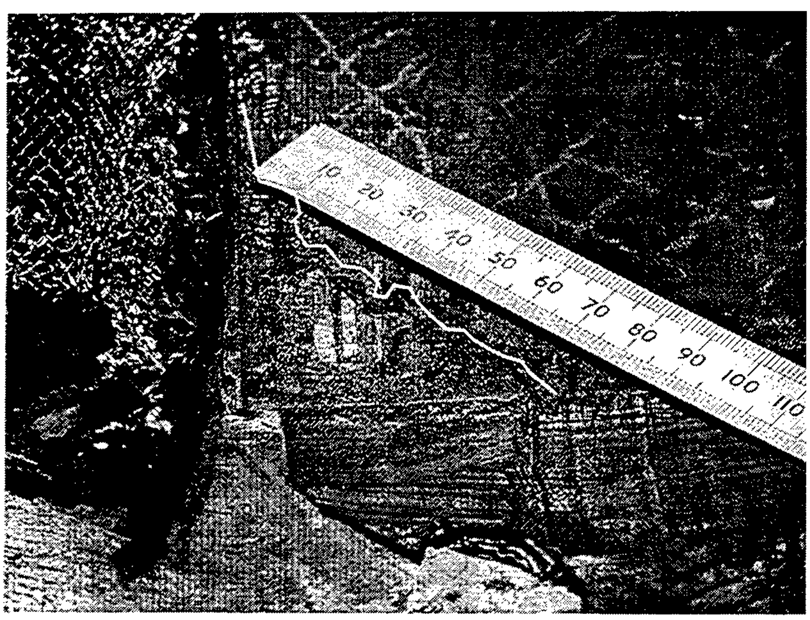

Figure 5. Central corner of the inboard edge of FWD doubler – A15-5.

This fibre breakage probably occurred during CPLT – similar evidence is seen in photographs of A15-35 doublers (AIR1/4080/A8/1101-5 Pt 5 (25)) taken soon after CPLT.

Figure 6 shows the central corner of the AFT doubler on A15-5. An offset white line indicates the position of fibre breakage.

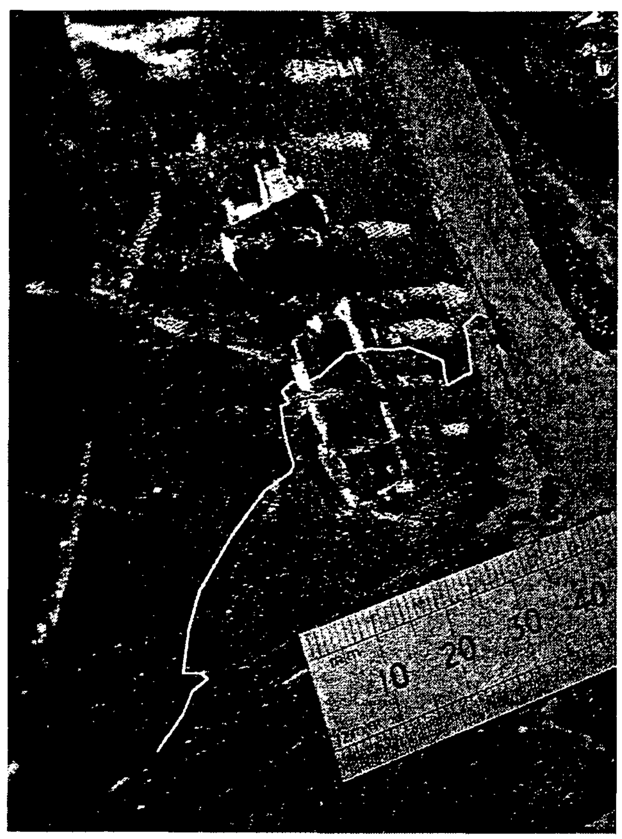

Figure 6. Central corner of the inboard edge of AFT doubler – A15-5.

Strain gauge positions can also be seen in Figures 5 and 6.

3.3 Inspection techniques

RAAF inspect the doublers using an ultrasonic NDI technique and the tap test. Discussions with RAAF personnel revealed that they prefer the tap test, as it seems to give more reliable results than ultrasonics.

The ultrasonics inspection of the doublers is carried out with the sheath removed. This inspection is carried out IAW RAAF AAP 7214.003-36-1. This inspection is carried out:

1. During S32 servicing which is carried out less than 100 AFHRS before a CPLT.
2. If excessive disbonds in sheath or the upper fill panel are found (using visual and tap test inspection techniques) during a service (usually R4 or R5) and the sheath is removed. Ultrasonic inspection is then done to check doubler for disbonds.
3. If a special request (such as request to waive an inspection on SRO2) is made and ultrasonic inspection is necessary.

Since inspection of the doublers is only carried out prior to CPLT which occurs every 2025 AFHRS it is possible that doublers on wings which have had approximately 1500 AFHRS are disbonded/delaminated and that they simply have not been discovered yet.

The tap test can be done with the sheath on but clearly some ambiguity arises as to whether the disbond indication is coming from the doubler or the sheath.

Experience gained at AMRL with wing A15-5 has shown that tapping through the sheath is reasonably accurate in the taper regions of the patch, however in the thicker sections, tap abnormalities may result from voids in the rubber compound that is used to bond the sheath on. In the tapered region where the rubber compound is applied more thinly, voids in the rubber compound are less likely.

3.4 Inspection intervals

The programmed inspection intervals are shown in table 3.
Table 3. Inspection intervals for F-111 aircraft

Inspection type	Inspection Interval
R1	100days
R2	275hrs
R3	525hrs
R4	1025hrs
R5	2025hrs
CPLT	2025hrs

The wing is removed from the aircraft for R4 and R5 servicing.

Currently the RAAF inspection interval for SRO2 (for which the doubler was meant to have some beneficial effect) is down to 525 AFHRS. The explanation for this is best summarised in RAAF minute: 501 WG/4080/A8/1101-5 Pt 2 (7), which states,

"The current policy for the SRO#2 is an inspection every 525 AFHRS, although, if the boron doubler fitted to the wing is serviceable, the interval can be increased to 1025 AFHRS. However, investigations by SRLMSQN (AFENG) and NDISL have revealed that considerable resources are required to fully develop an inspection method and reference standard that will produce satisfactory results. Furthermore, such an inspection method will involve considerable secondary maintenance, such as removal and re-installation of the boron doubler fill panels, filler blocks and sheath. Consequently, the resources required to ascertain the integrity of the doubler bond line exceeds that of inspecting the SRO#2 every 525 AFHRS. Thus, in terms of increasing SRO#2 inspection interval (given that in the event of an unserviceable doubler, SRO#2 must still be inspected), the boron doubler does not satisfactorily provide a solution. As a result, SRO#2 will continue to be inspected every 525 AFHRS. "

This minute also highlights the need for the development of a mechanically fastened sheath to make access to the doublers easier for more frequent NDI inspections.

3.4 Life to disbond formation

The seven wings with detected disbonds had between 729 and 1233 AFHRS service after fitment of the doublers. However, 21 other wings have had greater than 729 AFHRS service and 7 have had greater than 1233 AFHRS service. Disbonds may be present in these wings because NDI inspections are only required to be performed during S32 servicing every 2025 AFHRS. Therefore, it is difficult to estimate with certainty the life of the doublers before disbonds form. Disbonds when found tend to be quite large often extending from the outboard edge of the doubler inboard to the end of the splice (some 230 mm).

Based on the limited evidence available, external fuel tanks, which are used more frequently on RF111Cs, appear to hasten the formation of disbonds. Wings A15-3, A15-5 and A15-284 were on RF111C when disbonds were detected.

Given these factors it is difficult to be precise about the life of the doublers but the probability is that some disbonds form in less than 1000 AFHRS.

NDI of all wings with greater than 759 AFHRS would be desirable though not practical. A tap test of wings with high AFHRS may be more achievable.

4. Conclusion

The current investigation suggest that disbonds in the boron/epoxy doublers on the upper surface of F-111 WPFs are forming within 1000 AFHRS service. However, because NDI inspections of the doublers are only required to be carried out every 2025 AFHRS other wings, it is difficult to be precise. Seven wings have confirmed doublers disbond and a further five have had the status of their doublers reduced to partially incorporated.

The RAAF has lost faith in the doublers, setting the inspection interval for the critical SRO2 to be that if which no doubler were present. RAAF would like to manage SRO2 inspections without the need for the doublers.

If it is proven that it is necessary to have the doublers fitted to the fleet, then a better design of doubler, with improved inspection techniques and an easily removed fastened sheath will need to be developed.

Further investigation, looking at the applied loads on the wing due to external fuel tanks will be carried out.

5. References

1. Molent, L., Callinan, R. J. and Jones, R., "Design of an all Boron/Epoxy Doubler Reinforcement for the F-111C Wing Pivot Fitting: Structural Aspects", Composite structures 11 (1989) 57-83.
2. Pell, R. , "Examination of an F111 Boron Doubler", DSTO Publication DSTO-DDP-0167.
3. Molent, L. and Swanton, G., "A Parametric Survey of Cracking in RAAF F-111C WPF Stiffeners", DSTO Publication ARL-TR-55, Feb 94.

Appendix A

Figure 7 below shows the AMRL ultrasonic inspection results for the A15-5 doublers. Disbonds indicated by white crosshatched region.

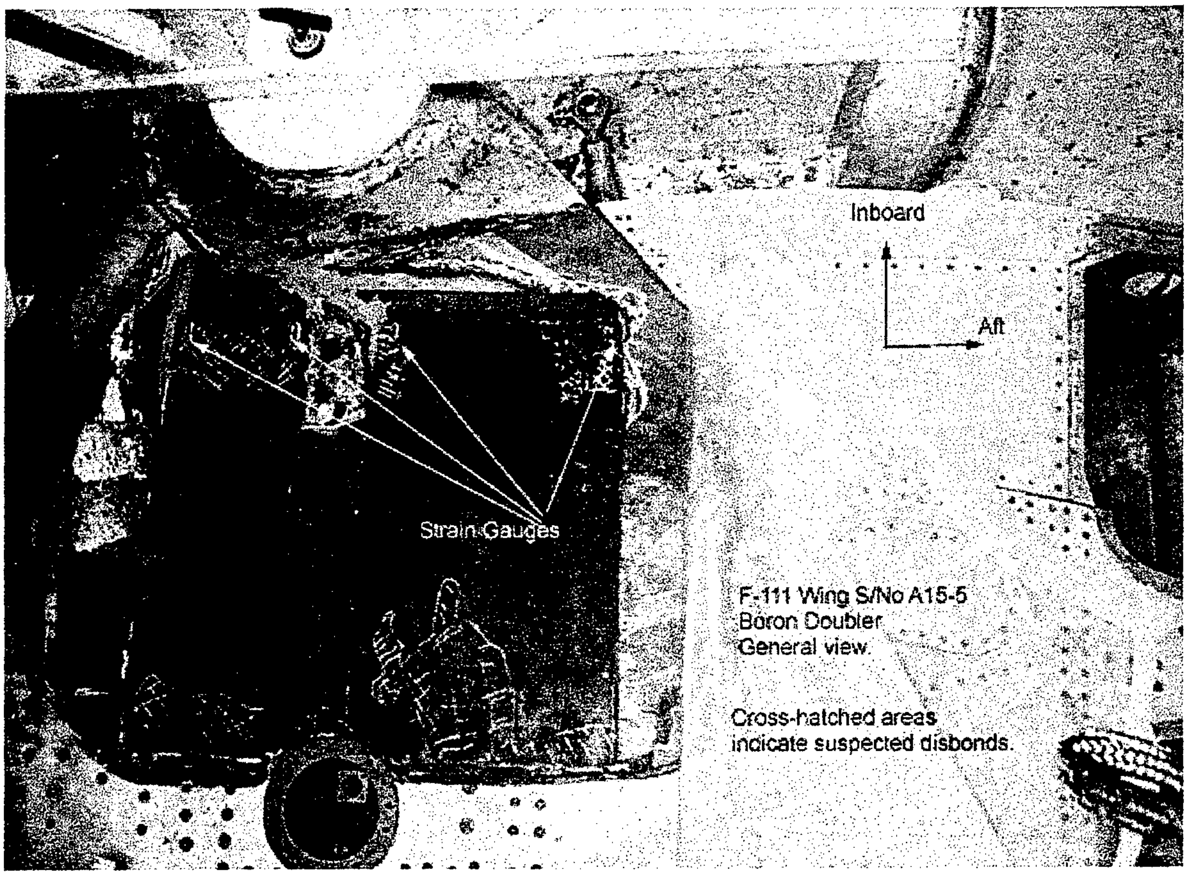

Figure 7. Results from AMRL ultrasonic inspection – ref F-111/Wing/01.

Figure 8 shows RAAF ref 501/A08C/11-01/A15-5 Pt1 (11) disbond map for A15-5 doublers after 932 AFHRS service.

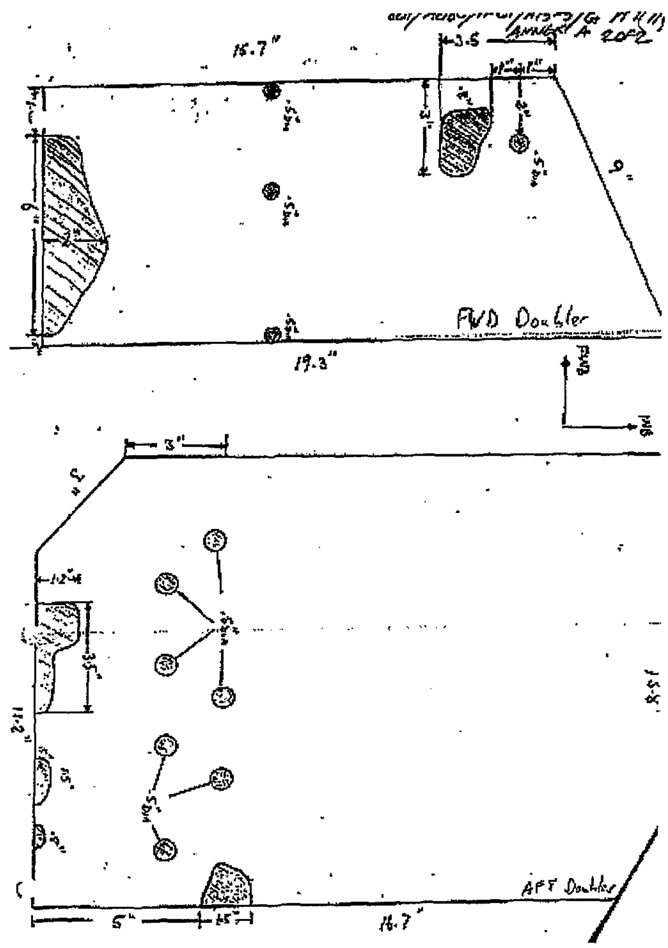

Figure 8. Extract from RAAF ref. 501/A08C/11-01/A15-5 Pt1 (11).

Note that the inboard area of the FWD doubler was reinspected and no disbonds were found there (RAAF ref. 501/A08C/11-01/A15-5 Pt1 (12)).

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Peter Chalkley and Rowan Geddes

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DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)
Service History of the F-111 Wing Pivot Fitting Upper Surface Boron/Epoxy Doublers	Document (U) Title (U) Abstract (U)

4. AUTHOR(S)	5. CORPORATE AUTHOR
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6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TN-0168	AR-010-643	Technical Note	September 1998

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
M1/9/553	98/188	DTA	15	3

13. DOWNGRADING/DELIMITING INSTRUCTIONS	14. RELEASE AUTHORITY
	Chief, Airframes and Engines Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

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16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

bonded composite repairs, composite materials, aircraft structures

19. ABSTRACT

Several of the boron/epoxy doublers applied to upper surface of RAAF F-111C wing-pivot-fittings (WPFs) have disbonded. Based on RAAF records, a total of seven wings (out of forty to which doublers have been applied) have confirmed disbonds: A15-3, A15-5, A15-10, A15-14, A15-19, A15-20 and A15-284R. Most of the disbonds are forming in the smaller forward doubler (five confirmed) although three aft doublers have also disbonded.

This report documents the service history of all doublers applied to RAAF F-111Cs. The current investigation suggests that disbonds in the boron/epoxy doublers on the upper surface of F-111 WPFs are forming within 1000 AFHRS service. However, infrequent inspections of the doublers make a precise determination difficult. Issues such as the use of external wing tanks on some aircraft (especially RF111C's), disbond initiation sites and below tolerance wing skin thicknesses are investigated.